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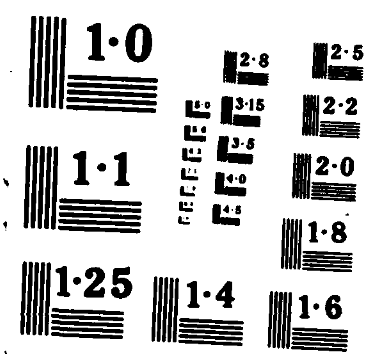
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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

AN INVESTIGATION INTO THE FEASIBILITY
OF A SPECIALIZED ALLOWANCE OF CRITICAL
SPARE PARTS
FOR GAS-TURBINE CLASS SHIPS

by

Karl W. Bogott

December 1987

Thesis Advisor David R. Whipple

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The possibility of developing a 'suite' of critical engineering parts to be carried by one of a group of Gas-turbine ships when deployed together has been raised. Such ships are sufficiently uniform in their engineering plants to make such a 'suite' feasible. The end purpose would be to lessen the possibility of a 'loss of mission' engineering failure by having low demand parts in theater. The inherent question is that of the performance of both current allowance computation models and the operating procedures which support those models. (To answer the questions, a test of the current COSAL model is compared with a similar test of a model more attuned to high levels of protection.) Allowance computation procedures are explored, as are those of the related essentiality measuring systems. The author presents the results of this test, conclusions drawn therefrom, suggestions for possible action and recommendations for improvements in current reporting procedures.

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An Investigation into the Feasibility of a Specialized Allowance of Critical Spare Parts for Gas-Turbine Class Ships

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The possibility of developing a 'suite' of critical engineering parts to be carried by one of a group of Gas-turbine ships when deployed together has been raised. Such ships are sufficiently uniform in their engineering plants to make such a 'suite' feasible. The end purpose would be to lessen the possibility of a 'loss of mission' engineering failure by having low demand parts in theater. The inherent question is that of the performance of both current allowance computation models and the operating procedures which support those models. To answer the questions, a test of the current COSAL model is compared with a similar test of a model more attuned to high levels of protection. Allowance computation procedures are explored, as are those of the related essentiality measuring systems. The author presents the results of this test, conclusions drawn therefrom, suggestions for possible action and recommendations for improvements in current reporting procedures.

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I. INTRODUCTION

Currently, when a battle group deploys, it does does not carry with it all of the major engineering parts that may be required in case of a part failure. When the group includes a(n Aircraft) Carrier, this has not been a serious problem. The needed part can be flown directly to the battle group on regular flights. When there is no carrier, however, there are longer delays and substantially greater costs involved in delivering such parts. Thus, the Navy would like to study the feasibility and the cost effectiveness of sending battle groups on deployment with 'pack-up' kits of major engineering ship parts -- as is now done for helicopters.[1]

A. PURPOSE

The purpose of this research is to determine if an alternative method can be determined which might provide for carrying a 'suite' of parts for systems, the failure of which might halt the mission of the vessel. By carrying a suite of spares uniformly available to a majority of ships in company, the Engineer's desire to have his spares on hand might better be met and transportation and supply system delays might be lessened for the delivery of critical, yet not-carried parts. Additionally, I propose to investigate any measureable change in effectiveness as a result of such a 'suite' of parts being in company.

B. OPERATIONAL VERSUS SUPPLY VIEWPOINT

In any shipboard environment, the viewpoints of the Supply Officer and the Engineering Officer may well differ with respect to which repair parts should be carried on board. In brief, the Supply Officer is charged with providing support from one of two sources. Either he has the part or material in stock, as provided by a Consolidated Shipboard Allowance List (COSAL), or he must requisition the required part or material from the Navy Supply System. The number of line items carried, (referred to, commonly, as ***range***), and the quantity of any individual line item carried, (referred to, commonly, as ***depth***), are provided by the COSAL models. These are used by Inventory Managers at the Navy's Inventory Control Point for ship's equipment, Navy Ship's Parts Control Center in Mechanicsburg, Pennsylvania. With limited exceptions, the Supply Officer has no control over range or depth of spares carried. The Engineering Officer, on the other hand, would, if he could, demand a complete set of spares be

[1]LCDR Joe Bouchard, USN, Destroyer Squadron 21, personal letter to Prof. James M. Fremgen

carried in his vessel to ensure that he would never break down. His uttermost desire would be for instantaneous service by the supply system. It is this polarity of opinions which provides the impetus for this research. Through investigating the possibilities of stocking parts for 'critical' systems, as defined by operating personnel, I hope to bring the more standard, statistically developed spare parts allowances into balance with the 'gut feel' of the operational personnel. This potential suite of parts is made more universally applicable and less 'hull-unique' through the standardization of engineering plants among the gas-turbine ships.

C. GAS-TURBINE STANDARDIZATION

The Navy has built four classes of ships utilizing gas turbine technology. These are the SPRUANCE class destroyers, the KIDD class guided missile destroyers, the OLIVER HAZARD PERRY class frigates and the TICONDEROGA class guided missile cruisers. Differing in mission, weapons configuration and supply support, the ships closely resemble each other in their engineering suites.

Within each class, the ships were constructed to be clones of each other. Each was built based on assembly line techniques. As such, their engineering plants are very uniform with respect to both physical layout and the equipment installed therein.[2] COSAL allowances are virtually identical between ships.

Between classes, the uniformity carries forward with respect to equipment installed. The PERRY class ships have engineering plants loosely approximating one-half that of a SPRUANCE. Ancillary systems differ more than the significant major elements of the propulsion plants. The TICONDEROGA class are built on SPRUANCE hulls. Their engineering plants are very similar to those of the SPRUANCE destroyers.

When a squadron of vessels is assigned a mission, it is conceivable, then, that a majority of the ships within that squadron might be made up of vessels with virtually identical propulsion plants. The propensity for duplication of supply support within the squadron is high. It also means that fewer very low demand, yet highly essential, parts might be required in the event of a critical engineering casualty among ships in the squadron. This similarity of critical need provides the basis for this research, in that one single suite of 'critical' spares would be applicable to numerous hulls.

[2]Information from the type-desk at SPCC indicates that future overhauls of the gas-turbine ships will permit deviation from the current standardization within the gas-turbine configurations.

D. PROBLEM EXPANSION

There are three additional concerns which add to the reason for exploring alternatives to the current methodology to provide not-carried spares to deployed units. These are Time, Transportation and Replaceability. These three elements can provide for unnecessary degradation of effectiveness and delays in repair of any system.

From the time any system fails for want of a not-carried part, the delay can be as much as seven days or more; even if the part is in stock at a retail stock point. Most of this time is related to communication and delay. For the systems which are the subject of this research, we assume that failure would cause a C-4 CASREP[3] condition, that meaning an inability of the ship to continue its mission. Such a CASREP requires submission of a message report and concurrent requisition for parts. These messages are subject to the routing priorities of NWP-3. After arrival, and screening, the requisitions are still subject to UMMIPS time standards. Without dealing in exact details of transportation, significant delay is experienced, even in shipping a part to a carrier-supported unit.

Transportation to a non-carrier supported unit can be a frustrating experience. In most cases, critical parts are flown by Military Airlift Command (MAC) aircraft. This requires diplomatic clearance of aircraft, but avoids customs problems. In the event of the necessary use of non-military air transport, it requires State Department intervention to clear parts through foreign customs. The delays can be measured in days. Again, without dealing in details outside the scope of this research, it is the writer's experience that shipment of critical parts in a foreign environment can add significantly to the cost of, and delay in bringing a critical system back on line.[4]

The replaceability issue is one worthy only of note in this research. In a C-4 situation, repair and replacement may be undertaken of parts and systems which are deemed, by the hardware designers, not to be repairable by the ship's maintenance personnel. Again, it is the personal experience of the writer that systems not requiring

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[3]The Casualty Reporting System, utilized by the Navy, requires a message report, a CASREP, for any degradation of the capability to perform it's mission. There are three classifications:

C-2 - equipment failure with negligible mission effect

C-3 - failure with significant degradation of mission effect

C-4 - inability to continue mission

C-3 and C-4 are considered major in scope.

[4]Use of the U.S. Postal Service avoids both the diplomatic and customs problems, but invites the delays inherent in utilizing the overseas postal system. Additionally, visibility is lost with respect to the whereabouts of the parts.

special purpose tooling, (such as that required in replacement of a Gas-turbine Generator), may be repairable. An example is the replacement, by USS CONOLLY (DD979), of two sets of shaft bearings while deployed off the coast of Chile in 1983. Replacement of these bearings was deemed to be a shipyard job requiring 36 hours of pier time. Following a 10 day delay, awaiting parts, CONOLLY personnel changed the first set in 26 hours and the second set in 18 hours.

E. RESEARCH QUESTIONS

In pursuing an answer to the general question of "Are the parts more valuable in theater than on the shelf?", this research will endeavor to answer the following questions:

1. Do current COSAL allowance models provide carried status for the 'most-likely-to-fail' critical parts?
2. If an alternate model were used would it provide greater range of critical parts?
3. Do any such parts exist in current Navy owned inventories in sufficient numbers to support an 'in-theater' repair parts 'suite'?
4. How should visibility on such parts be maintained?
5. Are there subjective elements of the model which effect its ability to meet its objective effectiveness goals?

F. PRESENTATION OUTLINE

I propose to present this research by using the following format within the body of this thesis.

This chapter contains the basic introduction with respect to the purpose, problem description and research questions.

Chapter II will present the basic methodology by which I intend to seek to answer each of the research questions posed in section E, above.

The next Chapter will present background information required to follow the methodology of the research. I intend to present a basic introduction to the Consolidated Shipboard Allowance List (COSAL) models used, and the basis for my investigation into the two methods used to determine the military essentiality of the systems and components included in the sample. With respect to the sample, my reasons and methods for selecting the sample systems and the methodology for selecting the parts to run through each model will also be discussed.

The results of the applications of and comparison between the models will be presented in Chapter IV, with any conclusions drawn, therefrom, enumerated in Chapter V.

Chapter VI presents a summary of the conclusions as they relate to the research questions stated above, and any recommendations made.

Following Chapter VI appendices will present the data bases upon which I conducted the research.

II. METHODOLOGY

A. PARTITIONING THE APPROACH

The Research Questions posed in Chapter I logically divide into three separate groups. Questions 1 and 2 follow, one from the other, in search of an answer to the possibility of determining a 'suite' of parts not, heretofore, selected by the existing model. Question 3 flows from a positive answer with respect to any increases in range resulting from the application of any alternative model, with the question of available inventory, question 4, following from there. Question 5 stands alone in questioning methods, and necessity for maintaining visibility on these parts.

To aid the reader in following the methodology, Figure 2.1 is provided as a flowchart of the process used to reach conclusions and/or recommendations.

B. MODEL COMPARISION METHODOLOGY

Answers to the research questions should flow reasonably from a comparison of COSAL allowance models. I propose to compare independent allowance computations for a sample of five Allowance Parts Lists (APL) common to all three gas-turbine ship classes. The two models selected are the .1 MOD-FLSIP model[5] and the allowance model utilized for the TRIDENT Strategic Missile Submarine. Chapter III discusses these models in greater detail. Comparison of the models first requires determination of Military Essentiality Codes for both systems and components. I propose to compute these codes independently using current CASREP and demand histories. These codes are essential elements of the allowance computations made within their respective models. Comparison of the two independently computed sample allowance lists will provide for conclusions to be drawn with respect to research questions 1 and 2.

Additionally, and pertinent to all conclusions drawn, should be the question of whether there is any benefit to be gained by carrying additional range.

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[5]The Modified Fleet Logistics Support Improvement Program model provides for stocking, as insurance items, those with annual demands greater than 1 over a 10 year period.

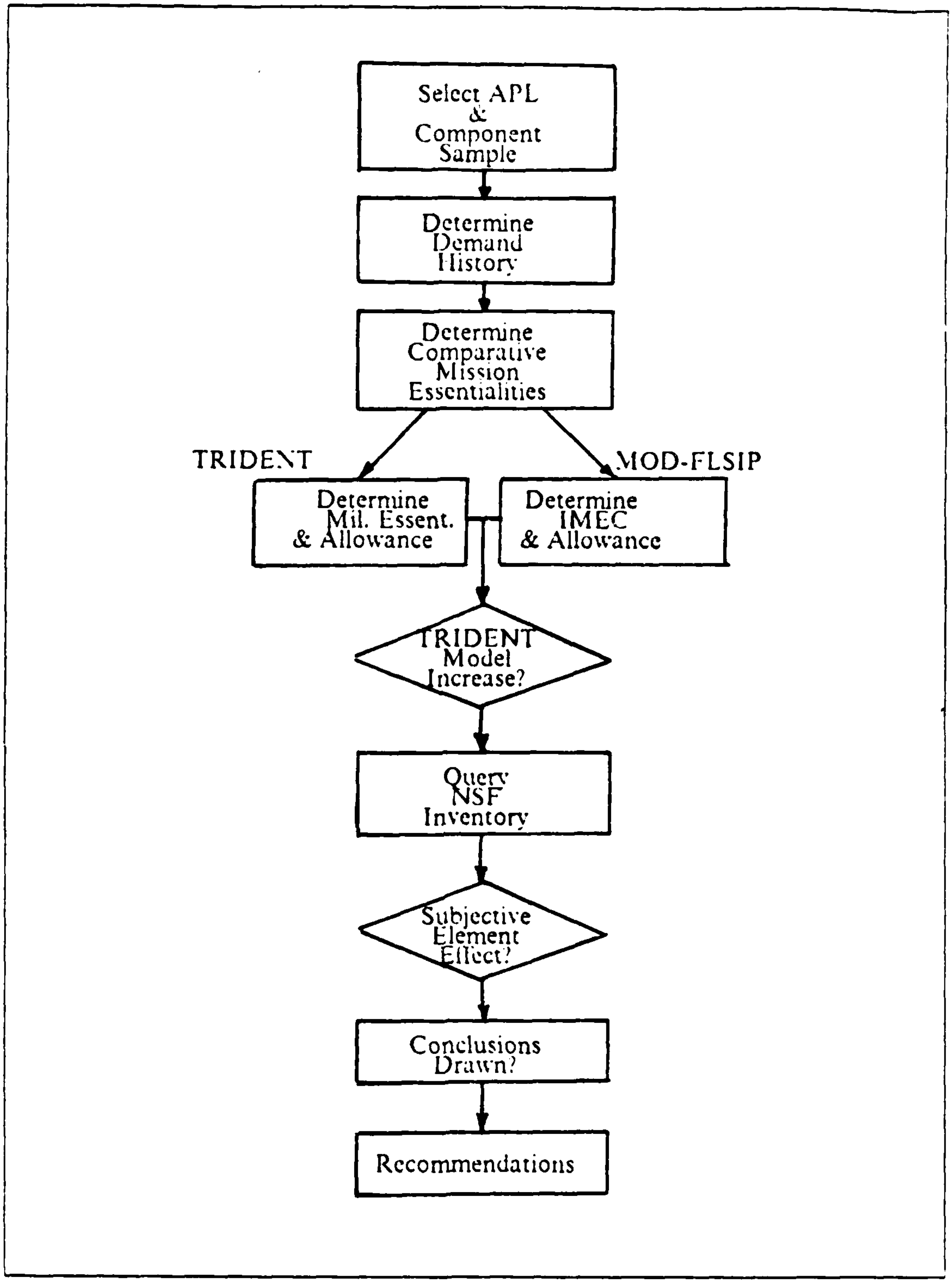

Figure 2.1 Methodology Flowchart.

C. SUBJECTIVE ELEMENTS IN THE STUDY

In the process of defining the method by which the research would be conducted, the possibility of one or more subjective effects upon model performance became evident.

- The actual effectiveness of the COSAL model is dependent upon the completeness and accuracy of the historical demand data.
- The allowance comparisons between TRIDENT and Mod-FLSIP will be effected by the different levels of support required for each, requiring adjustment of one or the other.

The effect that these subjective elements had on the research is noted in Chapter IV.

D. THE QUESTION OF INVENTORY VISIBILITY

Interviews with Squadron, Type Commander and Inventory Control Point (SPCC) personnel will provide the basis for my commentary on the best method of controlling any 'suite' of parts which should be selected by the model described, above. Question 5, although totally subjective in nature, is of importance when the potential cost, both in replacement and opportunity cost, is considered as a result of removing one Minimum Replacement Unit (MRU) each of any parts from stock.

E. BASIC DATA SOURCES

SPCC, Mechanicsburg, PA provided the vast bulk of parts data required for this research, including CASREP and APL data. Demand data was provided by Naval Sea Logistics Engineering Center, Mechanicsburg.

The data required to determine the surface Item Mission Essentiality Code was extracted from SPCC CASREP reports and computed in accordance with procedures outlined in NAVSUP Pub 533, *Inventory Management.* [Ref. 1: p. 4-40]

Information with respect to component-to-system and system-to-mission relationships required for the TRIDENT Mission Essentiality Coding was obtained from interviews with Type Desk, Type Commander and Squadron personnel.

Demand data required for allowance computation was obtained from the Naval Sea Logistics Engineering Center, Mechanicsburg, PA. The information was obtained from the 3M[6] files cross-referenced by APL.

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[6]The Maintenance Material Management (3M) system is charged with the collection of maintenance related supply data.

Finally, information on the allowed status of parts selected by the alternate model was obtained from the Provisioning Allowance Parts List. This data was obtained from the Master Index of Allowance Parts Lists provided by SPCC and Naval Supply Center, Oakland, CA.

F. FURTHER INVESTIGATION SOURCES

Special bibliographies were assembled by the Defense Logistics Information Exchange, Fort Lee, VA and by the Naval Postgraduate School Library. To obtain a better understanding of the allowance models in question, significant study was undertaken in both the Mod-FLSIP and TRIDENT allowance models, as well as their respective Military Essentiality Coding routines.

A review of current directives with respect to stocking policy, demand and insurance items was undertaken. Research Reports published by the Navy Fleet Material Support Office, Mechanicsburg, PA in the areas of concern were also reviewed.

III. BACKGROUND

A. MILITARY ESSENTIALITY CODE DETERMINATION

As early as 1958, studies were undertaken to determine the feasibility of utilizing an effectiveness criterion based upon the relationship of parts to their equipments and, subsequently, to the overall mission of the vessel for determining the appropriate mix of parts to carry as spares. [Ref. 2: p. i]

Virtually all other allowance models proposed since then, and all those concerned with this study, continue to be based, at least in part, on the mission value of a componenent to the vessel. The two allowance models I compared were based upon two different approaches to the question of mission criticality. The first considered is that currently in use within the surface community, the CASREP-based Mission Criticality Code.[7]

1. CASREP-based Mission Criticality Codes (IMEC)

In 1977, the Naval Sea Systems Command, NAVSEASYSCOM, and the Naval Ship Systems Engineering Station Detachment Mechanicsburg, NAVSSESDETMECH, proposed a new essentiality coding system based upon historical CASREP data. As noted earlier, a CASREP is a report made by the Commanding Officer of a unit advising higher echelons of command of equipment failure and the effect of that failure upon operational readiness. The result of those proposals was the establishment of the Item Mission Essentiality Code. The IMEC is an ordinal numeric code, 1 through 4, based upon a mathematic ratio of historic CASREP severities received over a ten year period. The IMECs were assigned as follows:

- IMEC 4 assigned if ratio of C3 + C4 to C2 CASREPs is > .2 *and* ratio of C4 to C3 CASREPS is > .33.
- IMEC 3 assigned if ratio of C3 + C4 to C2 CASREPs is > .2 *and* ratio of C4 to C3 CASREPS is < .33.
- IMEC 2 assigned if ratio of C3 + C4 to C2 CASREPs is < .2.
- IMEC 1 assigned if there are no reported CASREPs.

[7]Known as the Mission Criticality Code, MCC, it is actually a combination of the EIC level MCC and the component level Mission Essentiality Code, MEC. The combined code is the Item Mission Essentiality Code, IMEC.

IMECs were assigned at the Equipment Identification Code,[8] (EIC), level within ship class. The ship classes used for IMEC assignment grouped ships with similar systems and performing similar missions. [Ref. 3: p. 4]

For the purposes of this research, I wanted to determine whether the IMEC codings originally determined were still effective. Based upon the FMSO report [Ref. 3: Table III] the SPRUANCE class had only twelve IMEC 4 systems on-board of 519 systems. There were 86 IMEC 3 systems. This results in only 18 percent critical systems, based upon historical CASREPs. The PERRY class ships, newer at the time of the FMSO report had eight IMEC 4 and 43 IMEC 3 systems out of 147, for 34 percent of total systems.[9] I expected my research to point out that the operation's personnel view of systems as 'critical' would not be held by the supply system.

IMECs are assigned at the component, APL, level based upon mission impact in the event of component failure. Such assignments are the responsibility of the Hardware Systems Command and are based upon the matrix in Figure 3.1. [Ref. 3: p. C-1] The following definitions are included to understand terms used in Figure 3.1.

- Redundant systems refer to multiple installations of identical systems or components.
- Alternatives are not identical to the prime unit. They consist of alternative or emergency systems with the capability of permitting continuous operation of the system in the event of failure of the prime system. [Ref. 4: Encl. 1, p. 1]

The IMECs for both component and EIC levels figure into the insurance item computations of the COSAL allowance levels. The second Military Essentiality Coding system I needed to explore was that applied in the TRIDENT Strategic Missile Submarine System.

2. The TRIDENT System Military Essentiality Code (MEC)

The Strategic Systems Project Office designed a military essentiality coding system for the TRIDENT submarine based upon matching the component to system criticality with the system to mission criticality. The system was defined to be a ranking system, measuring the effects of parts failures on the capability of the TRIDENT submarine to perform its mission. Attention was focused, primarily, on the consequences of system failure on the sub's mission capability. Secondly, the effect of any single equipment on the parent system was defined.

[8]The EIC is a structured code assigned to identify shipboard systems, subsystems, and equipments.

[9]The Ticonderoga class was not in commission at the time of the FMSO report.

Redundant systems available	Alternatives (excluding redundancies) available	Neither redundancies or alternatives available	Impact if alternatives fail
3	4	4	Total loss of mobility
2	3	4	Severe degradation of mobility or loss of primary mission
1	2	3	Severe degradation of primary mission
1	1	2	Total loss or severe degradation of secondary mission
1	1	1	Minor mission impact

Figure 3.1 Criteria for Manually Assigning IMECs.

There are fourteen separate codes within the TRIDENT MEC system. These codes are based first, on assigned level of maintenance and, secondly upon individual item/system essentiality. The MEC codes assignable (37, 40, 43, 46, 49, 52, 58, 95, 98, 101, 104, 107, 110 and 116) are broken into two groups [Ref. 5: p. 6]. Those less than 95 are assigned to components with maintenance codes (similar to 3M repair/replace codes) denoting components which are not repairable or replaceable by ship's force. Those codes 95 or greater are assigned components which are ship's force capable. [Ref. 6]

These mission - system - component relationships are determined by a system of questionnaires completed by the appropriate engineering activity. The questionnaires construct a system couplet or an equipment couplet, as appropriate. Figure 3.2 is an example of the method used to determine the couplet applicable to the system or component. [Ref. 4: Encl 1, p. 5]

The MEC for each system or component is determined by taking the XY couplets for systems and components into a matrix, Figure 3.3, which assigns one of the seven eligible MECs. [Ref. 4: Encl 1, p. 6]

SYSTEM EQUIPMENT			
Identification ________			
Application ________			
Number Installed ________			
SECTION 1	Total Degradation	X=2	___
Mission Effect	Partial Degradation	X=1	___
(If ALL FAIL)	Negligible Degradation	X=0	___
SECTION 2	No Altern./Redund.	Y=2	___
Altern/Redund.	Reduced Effectiveness	Y=1	___
(IF ONE FAILS)	Equivalent Effectiveness	Y=0	___
System couplet = XY = ___			

Figure 3.2 Military Essentiality Questionnaire.

As in the case of the COSAL allowance computation, the MEC plays an important role in the determination of safety (insurance) stocks for the TRIDENT system. Details of these two allowance computation models follow immediately.

B. ALLOWANCE MODELS

1. Mod-FLSIP COSAL Allowance Model

COSALs are designed to provide an endurance level of support. Various allowance models are used to compute these support levels. The Fleet Logistics Support Improvement Program (FLSIP) model is currently used to compute allowances on non-Fleet Ballistic Missile ships. A slightly modified replacement model, the .1 MOD-FLSIP model, is being introduced as ships go through Integrated Logistic Overhaul (ILO).[10] The following is a discussion, summarized by Figure 3.4, of the process utilized by the Mod-FLSIP COSAL Allowance Model. [Ref. 7: p. ID3-10]

[10]ILOs were formerly known as SOAP, the Supply Overhaul Assistance Program. During ILO a ship's entire storeroom and issue system is removed, inventoried, upgraded and begun from scratch with a new COSAL, parts and paperwork.

SYSTEM COUPLET	00	01	02	10	11	12	20	21	22	COMPONENT COUPLET
	95	95	95	98	101	104	107	110	116	22
				95	98	101	104	107	110	21
					95	98	101	104	107	20
			95			95	98	101	104	12
							95	98	101	11
						95		95	98	10
									95	02
									95	01
									95	00

Figure 3.3 Military Essentiality Code Determination Table.

This model considers only ship's workforce installable items as allowance candidates. A 90 day demand forecast (μ) is computed for each candidate as follows:

$$\mu = (BRF * POP) / 4$$

Here, the BRF represents the Best Replacement Factor, an estimate of the annual usage rate for the part based on fleet-wide usage, and POP is the total part installed shipboard population across all component applications. Each candidate is the segmented into one of two categories -- demand based or insurance -- based upon its expected demand forecast. If the expected demand forecast is one or more units per quarter, the candidate is classified as a demand based item. Each demand based item is stocked in sufficient depth to provide 90% protection against stockout. If the expected demand forecast is less than one unit per quarter, the candidate is classified as an insurance item. Each insurance item is stocked only if its expected demand forecast is greater than or equal to a value known as the deep insurance criterion or exclusion

criterion. This value is currently set at .025 units per quarter (or .1 units per year). The Mod-FLSIP model also requires that an insurance item have a vital part to component IMEC and that the component to mission IMEC be vital, ie. each IMEC must be 3 or 4. Each insurance item which passes the exclusion criterion is stocked in a quantity of at least one MRU (Minimum Replacement Unit). Insurance items not passing the exclusion criteria are not allowed unless there is a Planned Maintenance Requirement or Technical Override. [Ref. 8: p. B-2]

In sharp contrast to the relative simplicity of the Mod-FLSIP COSAL Model, the TRIDENT model requires much more detail for understanding. I propose to present only as much as is necessary to grasp the concepts used in the model for this research. Much greater detail is contained in Enclosure 1 of Reference 6.

2. The TRIDENT COSAL Model

An immediate difference in philosophy is apparent between the FLSIP model and the TRIDENT model in that different protection levels are prescribed for parts based upon their MEC. Whereas only two differentiations are made in the FLSIP model, six different levels exist for the TRIDENT model [Ref. 6: Encl. 2, p. 1-5]. These protection levels are shown in Table 1.

Two determination calculations are used in this study. First that for COSAL quantity:

$$\text{COSAL QTY} = .5 + D + \{ 8.8 - 1/6\,(116\text{-MEC}) - 1.5\,\text{LOG}_{10}\,P\} * D^{1/2}$$

$$D = \text{Average Demand} \qquad P = \text{unit price}$$

The .5 in the formula assures that, after rounding, at least 1 MRU will be stocked for all items with a MEC > 95. Average demand (D) is a 90 day forecast based on the BRF and the population. I used the same (μ) figure computed in the Mod-FLSIP model for the sake of continuity.

The second calculation of which I took note was that for safety level (S):

$$S = .5 + \{8.8 - 1/6\,(116\text{-MEC}) - 1.5\,\text{LOG}_{10}\,P\} * u^{1/2}$$

$$P = \text{unit price} \qquad u = \text{average number of failures}^{11}$$

If MEC = 95 then $S = 1.3 * u^{1/2}$

[11] I interpreted this to be average demand (D) over the period.

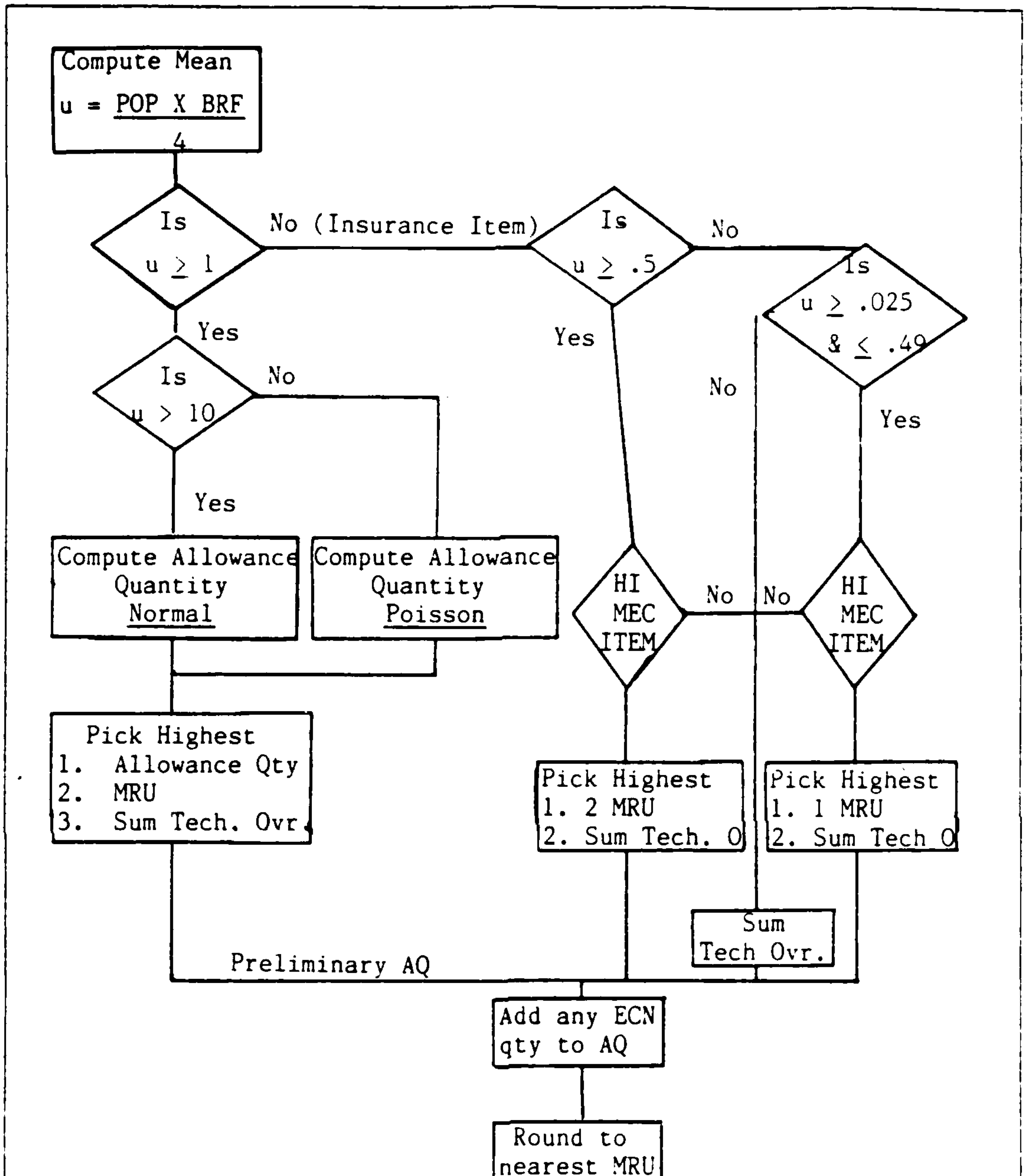

Figure 3.4 .1 MOD-FLSIP COSAL Model Allowance Quantity Computation.

Source: SPCCINST 4400.30C, 11 FEB 1982, p. ID3-10

TABLE 1

NOMINAL TRIDENT PROTECTION LEVELS

MEC	*Nominal Protection Level t*
116	.9999
110	.999
107	.99 < t < .999
104	.99
101	.9 < t < .99
98	.9
95	.9

The following paragraphs explain the rationale behind the complex safety formula. The model assumes demand to be Poisson distributed. Simplification of the quantity determinations is made by using the Normal approximation of the Poisson:

$$D = \mu + t\sigma$$

where

μ = 90 day expected demand

t = Normal standard unit -- measurement of standard deviations from the mean

σ = standard deviation of demand

Since it was assumed that demand was Poisson distributed, the standard deviation is equal to the square root of the mean. Therefore the above formula becomes:

$$D = \mu + t\mu^{1/2}$$

In fact, it is in this form that allowances for MEC 95 items are calculated with a t equal to 1.3. The expanded formula, above, is utilized to approximate the greater values of t required for the higher levels of protection. See Table 2 below. [Ref. 8: p. B-7]

TABLE 2

CORRELATION OF T VALUE TO PROTECTION LEVEL

Value of t	Protection Level
1.3	90%
2.3	99%
3.3	99.9%
4.3	99.99%
5.3	99.999%
6.3	99.9999%

The Poisson approximation function for the safety level (S) does not permit the protection level to be varied depending on the price of the item. The '1.5 LOG_{10} P' is an adjustment made to the constants in the Poisson function to take into account the value (P) of the individual component. [Ref. 6: Encl 2, p. 1-4]

The quantity of spares required in the TRIDENT model is determined to be

$$Q = D + S.$$

I determined this to be the allowance quantity, and it was these quantities I compared against the computations from the Mod-FLSIP model.

My next problem was to determine which systems, uniform to all three Gas-turbine ship classes, would be used in the study.

C. SAMPLE SYSTEM DETERMINATION

The purpose of this research, as stated at the beginning, was to determine the feasibility of developing a 'suite' of critical parts uniform to systems within the engineering area. An additional condition was a minimum of three APLs. I wanted a mechanical system, an electronic system and a control system. These represented a broad spectrum of the engineering plant of the gas-turbine ships, based upon my own experience. My research sponsor, Destroyer Squadron 21 in San Diego, CA, responded to my request with five different APL numbers, among which was one system which their engineering personnel considered to be especially critical. These five systems, (subsystems, really, of the Gas-turbine propulsion plant) are listed in Table 3.

TABLE 3

SYSTEMS SELECTED FOR RESEARCH

APL Number	Short Name
701110382	GTM - Main Fuel Control
701110383	Compressor Inlet Temp Sensor
052050008	GTM - Fuel Manifold Piping
616050177C	F.S. Elex Control Torque Computer
616053178C	Alfa Circuit Fuel Scheduler

I requested a CASREP report from SPCC for the USS SPRUANCE (DD963). The makeup of the report requested was for all reported CASREPs over the last five years for the specified hull. SPRUANCE was selected because she is the oldest ship in the class. The CASREP report would provide the study with initial information, both objective and subjective, upon which to base selection of individual components to test. Additionally, I required CASREP data to determine the MCC, MEC, and IMEC for allowance computations. As mentioned in Chapter II, I intended to utilize demand history from 3M reports to compute allowances for the selected APLs, based upon the IMECs and/or MECs computed from the CASREP reports.

D. SAMPLE COMPONENT DETERMINATION

As mentioned in Section II.E, above, the Navy Maintenance Material Management (3M) system gathers demand and maintanance information independently of the supply system. In brief, a non-mechanized ship is required to submit one copy of the 1250-1 requisition to the 3M system for any parts utilized in a maintenance action. It is this submission of parts data to the Navy Maintenance Support Office, (NAMSO), which provides for the accumulation of demand data, over time. The accuracy of this data will have a decided effect upon the ability of the COSAL model to adjust for actual demands. This demand data is utilized to update COSAL data when the ship undergoes an Integrated Logistics Overhaul (ILO).

I requested a NAMSO 4790 Report, Parts Report, from the Navy Sea Logistics Center, Mechanicsburg, PA. It is this division of NAMSO which maintains the demand files. The report I requested was for the past ten years demand of all parts

applicable to the five APLs, for USS SPRUANCE, under research. Ten years of data was required to allow computations in the Mod-FLSIP COSAL model.

The information received delineated every requisition, by National Item Identification Number (NIIN), as well as summarizing by NIIN, within APL. In order to determine the projected cost of a 'suite' of parts, current unit price data was also included. In the event I needed to cost out the 'suite', I was prepared to check the most current Master List Navy, ML N.

The final requirement was to query the supply system with respect to availability of parts in the 'suite'.

E. NAVY SUPPLY SYSTEM PARTS AVAILABILITY

The Navy Ship's Parts Control Center, SPCC, maintains stock visibility on all Navy managed stocks of ship repair parts. Those NIINs with COGs 9- or 5- are part or the Navy Retail Supply System and are managed by DLA, GSA or other Armed Services. For those NIINs, individual stock points maintain visibility of their own inventories. For the purpose of this study, I intended to query NSC San Diego and NSC Oakland for inventory status of 'suite' parts.

F. VISIBILITY METHODOLOGY

The original question posed by DESRON 21 alluded to the packup kits common in the aviation community. These are aggregations of parts, insurance items, demand items and those required for preventative maintenance which might be required by the embarked aviation detachment during the projected period of operations. In the case of the packup kits utilized by the anti-submarine helicopter detachments which might be embarked in a gas-turbine warship, visibility of the inventory is maintained by the Naval Air Station (NAS) supply department to which the detachment is attached when not embarked. Requisitions for replenishments of line items drawn from these packups are forwarded to and filled from the stocks of that NAS. Since no like symbiotic relationship exists between the Gas-turbine ships and an NSC, a discussion of how, or if, visibility of a 'suite' of parts was required and will be undertaken in Chapter V.

G. COMMENTS ON THE RESEARCH BACKGROUND

The supply system components investigated, allowance calculation, material essentiality computation, and CASREP and demand reporting are all well documented, functional subsystems of the infinitely more complex Navy Supply System. There are well-intentioned and well thought out interrelationships which are intended to provide

cross-referencing and cross-checks on the millions of transactions occurring annually. I expected to find, as my research began, a simple progression of data which would allow me to make a judgement on a ship class level of the effectiveness of one allowance computation method against another. I expected the subsystem components mentioned above to provide the study with the data, interrelated as intended. I did not expect to find major disconnects between the system components. This was not to be the case.

IV. RESEARCH RESULTS

Recall that the purpose of this research was to determine the feasibility of providing improved supply support to specific systems. The plan was to specify a methodology by which to explore the model currently in use and to compare it with an alternative model, proceeding in a fashion which approximated the prescribed procedures for determining onboard allowances. The following sections will, sequentially, deal with the essentiality question, the COSAL allowance computations, comparisons thereof and finally, the issue of any subjective elements to the problem.

A. MISSION ESSENTIALITY CODE DETERMINATION

A Caveat. The IMECs and MECs determined in this study are not necessarily those which would be determined by the respective hardware systems commands, but do represent a faithful test against the criteria laid down by the Strategic Systems Program Office for the TRIDENT system and the Naval Sea Systems Command for normal surface ship systems.

I determined an Item Mission Essentiality Code for each of the selected APLs by entering redundancy and mission criticality assumptions about each into the MEC selection matrix previously displayed as Figure 3.1. Table 4 below displays the results of that determination.

TABLE 4
SELECTED APL ITEM MISSION ESSENTIALITY CODES

APL	*MEC*
616050177C	3
616050178C	3
652050008	3
701110382	2
701110383	2

It was noted in Chapter III.A.1, that relatively low MEC assignments were made to what might otherwise be considered essential systems. This was not unexpected, given the redundancies and alternatives built into the Gas-turbine class vessels. (See Chapter III, section A.1.) However, it did impact on what parts would automatically be allowed by the Mod-FLSIP COSAL model. Components of systems with low (2 or 1) MECs were not allowed as insurance items unless so designated by Technical Overrides, while high MEC systems allowed far more insurance items as a consequence of the model. This difference in allowance criteria was indicated in Figure 3.4.

Additionally, there is no room in the IMEC calculation for subjectivity on the part of the supply system. The code determination is completely determined by the number of CASREPs reported, over time. In the case of the data used in this effort, two APLs reported no CASREPS over the period of study.[12] Regardless of criticality, the system prescribed *will assign an IMEC of 1.* In this case, APL 616050177C, the Free Standing Electronic Control Torque Converter, has an onboard population of only one. The engineering personnel in the squadron consider it to be an essential and undersupported system. However, it has no reported CASREPS and, therefore, an IMEC of 1. No such impediment to establishing a relevant essentiality was apparent in the TRIDENT coding system.

Each of the components listed in the demand history reports from NAMSO was subjected to the selection criteria laid out in Figure 3.3, both from a system and a component criteria. Table 5 summarizes the distribution of MECs determined for the sample of components in this research effort.[13]

It is apparent that no MEC of 104 was assigned. An explanation of this phenomenon is found in the requirements for a 104 MEC. For the one system with a system couplet of 22 to have any parts with a 104, it would have been necessary for the failure of a part with no redundancy or alternatives to have resulted in just a partial degradation. For the other systems, each assigned a system couplet of 21, a 104 MEC would require redundancy or alternatives, but total degradation if all failed. These two situations did not occur in the data obtained from the demand history. There was no significance in the lack of any 104 MECs. Note should be taken that the only 116 MECs occurred where the one system with a 22 couplet also had components with 22 couplets. The TRIDENT system is very stingy with its highest MEC.

[12]See Appendix C for a listing of the CASREP information utilized in this study.

[13]A complete listing of MEC couplets and assignments is included in the TRIDENT COSAL Allowance Determinations, Appendix B.

TABLE 5

TRIDENT COMPONENT APL MECS

	MEC							
	95	98	101	104	107	110	116	TOTAL
APL								
052050008	8	13	21	0	6	39	0	87
616050177C	0	0	0	0	0	0	2	2
701110382	1	3	0	0	8	5	0	17
701110383	0	0	0	0	3	1	0	4
616053178C	No Demand History							

Having established a baseline of mission essentiality codes for the sample components and APLs, the next item to pursue was the calculation of independent COSAL allowances from the two selected models, the in-use Mod-FLSIP model and the TRIDENT COSAL model.

B. COSAL ALLOWANCE CALCULATIONS

1. The Data and the Calculations

110 individual components were provided by the Demand History report obtained from NAMSO. No data was reported for one of the APLs. Only 1 APL provided a significant amount, 87 line items, of data. One other provided 17 line items. Since these were the APLs provided by the original sponsor of the research, I decided to restrict the modeling to them, even though the data was sparse. The main reason for the decision was that there was, obviously, a perception of a lack of support for these APLs. Therefore, the question of possibly improving support for them still held, and, in fact, the paucity of data was, itself, a part of both the answer and the conclusions drawn therefrom. This aspect will be dealt with in Chapter V.

Calculations were performed on an Apple IIE microcomputer, utilizing the APPLEWORKS integrated spreadsheet. Sample calculations were manually performed to check the accuracy of the computerized models. Complete listings of the

calculations and subsequently obtained allowances are displayed in Appendix A, for the Mod-FLSIP COSAL model, and Appendix B, for the TRIDENT COSAL allowance computations.

A Caveat. As with the IMEC and MEC determinations in the previous section, the allowance calculations made within the scope of this research may not be those determined by the respective hardware systems commands. Original MEC determinations were made on engineering estimates. The MECs utilized in this project were calculated utilizing the prescribed formulae, as directed by the appropriately noted references.

2. **Performance of the Models**

The most important result obtained from the Mod-FLSIP calculations was that **every single line item in the demand history was allowed** as either demand based or an insurance item. The models functioned exactly as designed, designating few demand based allowances, yet providing safety levels of support.

Specifically, in the case of APL 052050008, 8 of 87 components listed, 9.1%, were calculated to be allowed as demand items. All of these components were items, such as gaskets or packing, which were determined to be Preventative Maintenance System (PMS) items.

Also of significant note was that no 7H cognizance Depot Level Repairables (DLR) were picked up as demand items. Three of the APLs are very dependent upon printed circuit systems. Within the body of the sample data, 11 line items, 10%, were 7H, (or 2H), yet none were in the 9% selected as demand based. This was attributed to the predominance of PMS items in the demand based selections and to apparent reliability of system components.

Application of the TRIDENT COSAL model took place in two parts. First, application was made without modifying the vastly superior protection levels provided by this model. This was done because of the premise provided by the thesis purpose, improved support. Obviously, this improved level of performance would entail additional inventory cost. Secondly, the model was reapplied with protection levels approximating those of the Mod-FLSIP model, 85%.

The TRIDENT model differs in operation in that it computes a single allowance, rather than differentiating, specifically, between demand based and insurance. This single allowance can be broken into its demand and insurance quantities, as noted in III.B.2, above. A complete listing of the computed allowances, in their component parts is provided in Appendix B.

In almost all instances, the safety quantity exceeded the demand quantity computed, a product of the safety level computation. Specifically, only those NIINs with a computed MEC of 95 provided for demand levels in excess of the safety level. This is indicative of the significantly increased protection levels provided by the MECs greater than 95.

The effect of the price moderator noted above was evident in the quantities allowed. One specific example of the moderator effect is shown in Table 6.

TABLE 6
TRIDENT PRICE MODERATOR EFFECT

NIIN	PRICE	MEC	μ	DEMAND	SAFETY	ALLOW
00-118-3177	$.14	101	.1	.4	2.6	3
00-118-3177	$14.00	101	.1	.4	1.6	2
00-118-3177	$140.00	101	.1	.4	1.1	2

While a price increase does not necessarily elicit a decrease in safety level of the same relative magnitude, the moderator effect *is* obvious. Another effect on the safety level was that caused by the lessening of the protection levels in the second iteration of the TRIDENT model.

The model formulae were modified to provide for each NIIN to have a forced MEC of 95. Additionally, the safety level formula was changed to:

$$S = 1.04 * u^{1/2}$$

The change from 1.30 in the original formula for a part with a MEC of 95 to 1.04 reflects the change from 90% to 85% protection, (a Normal Z value), thus simulating the Mod-FLSIP levels.

The results of this recomputation were two-fold. First, 64% of all allowances were reduced by approximately 20%. Only 31 of the allowances did not change as a result of the lowered protection levels. These were those which already had MECs of 95 or 98, or were accounted for by the rounding process.

The second result was that of a reversal of weight within the allowances themselves. By shifting the burden of protection away from the safety level, a much

greater emphasis was placed on demand in the computations. The result was higher demand levels and concurrently lowered safety levels. This shift was evident even in the NIINs which did not change allowances overall.

To briefly summarize the results of the respective allowance computations, the TRIDENT model showed much more propensity to take into account price and protection level within its calculations, even when the TRIDENT-inflated protection levels were deflated to a normal 85%. It remained to compare the two separate computations with a view toward answering research questions 1 and 2.

C. COMPARING THE MODELS

In the first instance, with the TRIDENT model running unrestricted, support was more than doubled for most line items over that provided by the Mod-FLSIP model. Even those with MEC of 95, approximating a 90% protection level, doubled the support of the Mod-FLSIP model.

In the second iteration of the TRIDENT model, that approximating the same protection levels as the Mod-FLSIP model, support still remained higher (data not included). Even though there was a significant lowering of allowances, the TRIDENT model still provided at least twice the depth of the Mod-FLSIP computations.

Conclusions drawn from the above data will be enumerated in the next chapter, however, certain significant items are summarized below as a baseline for those conclusions and subsequent recommendations.

- CASREP history shows either good support or good reliability for the APLs selected.
- Demand history shows relatively light demand for components of the 'critical' APLs.
- The Mod-FLSIP model will provide, at ILO, an allowance for *every single NIIN reported.*
- The TRIDENT model provides at least double the support, even at the same protection level.

One final fact of great importance in later discussions of subjective elements in the models is that **the only NIINs common to both CASREP reports and the Demand History reports are those which are already allowed in the ship's COSAL.** All other NIINs required by the CASREPs, those **not currently allowed** in the ship's COSAL, do not appear in the demand history.

V. RESEARCH CONCLUSIONS

This chapter presents conclusions drawn as a result of the research effort. The conclusions will be related to the specific research questions posed and, ultimately, to the purpose of this research, the feasibility of determining and establishing a 'suite' of repair parts for critical engineering equipment. To facilitate establishing these relationships, a restatement of the original research questions may be helpful.

- Do current COSAL allowance models provide carried status for the 'most-likely-to-fail' critical parts?
- If an alternate model were used would it provide greater range of critical parts?
- Do any such parts exist in current Navy owned inventories in sufficient numbers to support an 'in-theater' repair parts 'suite'?
- How should visibility on such parts be maintained?
- Are there subjective elements of the model which effect its ability to meet its objective effectiveness goals?

A. QUESTION 1 -- COSAL SUPPORT

With respect to question 1, that of the sufficiency of the current model in supporting 'most-likely-to-fail parts', I must conclude that the .1 Mod-FLSIP COSAL model currently in use does meet requirements. The following is offered in support of that conclusion.

- Based upon the data obtained, every part with historical demand over the last ten years was selected for allowance. The selection may have been as demand-based or a one or two MRU insurance item, but the fact remains that the COSAL model did allow stockage.
- Within the classes of ship studied, redundancy and alternative solutions are sufficient to further reduce the criticality of systems, with respect to a 'mission-crippling' casualty. Only one of the APLs submitted for research was not protected by a duplicate or redundant system which would allow mission continuance.
- Reliability of the systems submitted for study appears to be high. The historical demand file lists very few parts required for maintenance actions. The Total column of Table 5, lists the number of NIINs by APL. The average number of NIINs required per year ranged from .2 to 1.7. The exception, APL 052050008, requisitioned an average of 8.7 NIINs per year. This led to one of two possible conclusions: First, that the systems were reliable or; second, that demand data was not being submitted to the 3M system. This latter possibility will arise again, with respect to question 5.

- I concluded, based upon the data available, that the systems were well-supported by the onboard allowance. Appendix C displays the low number of CASREPs reported.

B. QUESTION 2 -- ALTERNATE MODEL IMPROVEMENT

Given that the model in use apparently provides sufficient support, the question of improved range from an alternative model appears moot. However, the following conclusions are offered for completeness:

- No improvements in range were made in the limited application of an alternative model, the TRIDENT COSAL model, to the data in hand. The data displayed in Appendices A and B support this conclusion.
- The apparent improvements in depth offer no improvements in support for the systems under study. Even when the protection levels were reduced to a comparable 85%, depth was still doubled on most NIINs.

A final summary conclusion may be drawn:

Given that, by virtue of being demanded, every NIIN demanded then qualifies for an allowance under the current model, no arithmetic method can be determined, based upon demand or CASREP-based criticality, which can justify a 'suite' of parts. Therefore, it is infeasible to determine, at least statistically, a 'suite' of repair parts.[14]

C. QUESTION 3 -- INVENTORY AVAILABILITY

I drew two conclusions with respect to inventory availability. The first was the question of parts being available in the wholesale system. Since no additional parts could be defined as a 'suite' no query of system resources was possible.

Second was the question of onboard stockage. Ten of the twenty NIINs reported by CASREP were not-carried items. (see Appendix C). Thus, we may conclude that onboard inventories and allowances are insufficient to preclude casualties. However, the significance of no reported demands for not-carried CASREP demands being reflected in the demand history, cannot go unnoticed with respect to

[14]The U.S. Navy Supply Corps ethic tends to be that to say 'No!' to a request without offering an alternative means to the desired end is to admit failure, a lack of innovative thought and no initiative. As a result of the research, I determined that a specific model could be applied to any selected list of NIINs to determine if they would be individually worth carrying and, en masse, worth the effort, overall. This model is discussed in Appendix D, as an alternative. It is a 'quick and dirty' model for determining which NIINs might qualify for technical overrides, based upon 'maintenance feel', mission essentiality and cost. Because of the vague nature of these elements, I do not recommend use of this model without further study.

this question. This apparent failure of the demand reporting system is the subject of conclusions to question 5.

D. QUESTION 4 -- 'SUITE' VISIBILITY

In the introduction to the idea of a 'suite' of parts, the 'pack-up kits' utilized by the aviation community and the relationship between the squadron and the NAS was discussed. It was noted, at that time, that no such relationship existed between ships and their stock points.

Theoretically, there are various alternatives to the question of maintaining system visibility on any 'suite' of parts designed to serve the purpose of this research.

- The 'suite' may be maintained in the Navy Stock Fund, with the visibility of any other line item managed by an Inventory Manager.
- The 'suite' may be drawn, as end-use, by the Type Commander concerned. As such, visibility would no longer be available to the system, as a whole, but rather to the Type Commander.
- The 'suite' may be drawn, and maintained, by select hulls within the squadron. Visibility is lost, except by report to the squadron and/or Type Commander. Such a 'suite' allowance would have to be authorized by technical override.

The first alternative is unacceptable. There is no current mechanism for maintaining visibility of NIINs on any platform other than those carrying Special Accounting Class (SAC) 207 or 230 Navy Stock Fund Inventories. These ships, AFS, AO, AE, AOE, etc., have Navy established mechanisms by which visibility of the stocks carried is maintained, at least quarterly, the the Navy Supply System. To modify any such system for a 'suite' of only a relative few parts is not feasible, nor is it cost effective.

The third alternative is equally unacceptable. Since the current COSAL model allows stockage of those NIINs determined most likely to be needed, removing other NIINs from visibility, on an individual platform basis, is equally cost ineffective.

In the event that any such 'suite' is devised, (utilizing the alternative prescribed in Appendix D or any other method.) I conclude that only the Type Commander should fund and maintain visibility of such 'suites'. In brief, if a casualty on any platform in company with such a 'suite' should occasion an issue of a NIIN from the 'suite' than the Type Commander should requisition a replacement part. Such activity should be part of the CASREP process to assure a record of significant maintenance and sufficiently visible to assure that usage be recorded against the demand history in the 3M files. It is this final recommendation for demand visibility which leads to the conclusions to question 5.

E. QUESTION 5 - SUBJECTIVE EFFECTS ON THE MODEL

It was surprising to note during the modelling effort that no 'not-carried' NIINs reported in CASREPs were recorded in the demand history. To any experienced Supply Officer, this leads to only one conclusion:

- **CASREP demands are not being reported to the 3M system, in accordance with the standard operating procedures for requisitioning parts required for maintenance actions.**

Within the body of those procedures is a requirement to submit a copy of the original requisition to the 3M system. It appears that the high visibility and the pressure for speed of a CASREP requisition can result neglecting to complete the requisition loop prescribed. In brief, the Supply Officer, or one of his senior personnel, normally handles a CASREP. The requisition is handled in an 'off-line' fashion and is either phoned or submitted in non-MILSTRIP message format directly to the Inventory Control Point. It appears that only the obligation and outstanding requisition file copy of the original document are retained, since these documents are traceable, while the 3M document is not.

The end result of this omission is that demands for critical parts, those required for casualty corrective maintenance, but which are not allowed, are never reported to 3M and are, therefore, **never a part of any recomputation of COSAL allowances.**

Therefore, **any judgement of the effectiveness of the COSAL model in meeting demands for 'critical' parts is severely hampered by the significant failure of prescribed administrative procedures to properly record critical demands where the system might act upon them, as it is designed to do.**

VI. RECOMMENDATIONS AND SUMMARY

The original purpose of this research was to determine the feasibility of designing a 'suite' of critical engineering parts to be carried in company with a group of gas-turbine ships. These parts were to be those which were not eligible for a COSAL allowance and, yet, were considered to be critical to the preclusion of a mission-threatening casualty. The fact that the engineering plants of three complete classes of gas-turbine ships are uniform lent a certain reasonableness to the proposal.

To determine this feasibility, I have investigated the current COSAL model to determine the characteristics required to qualify for an allowance. I have investigated an alternative model which relies more upon the criticality of a part than upon its historical demand to determine allowability. During the investigation, and subsequent testing of data against both models, I discovered that the current model will, at the next ILO, provide adequate COSAL coverage for any component which has established a historical demand. Additionally, I discovered that the ability of the model to perform adequately has been hampered by a failure in administrative procedures. As a result, I make the following recommendations.

A. RECOMMENDATIONS

Recommendation 1 -- CASREP histories for the APLs selected as critical be requested for all concerned ships. Additionally, Demand Histories for selected APLs, cross-referenced to all concerned ships, should be requested. A cross-reference effort should be undertaken to:

- identify NIINs required for CASREP correction, the demands for which do not appear in the history,
- identify not-carried NIINs which might be considered for any subsequent technical override allowance, and
- determine whether proposed 'critical' APLs display any history of failure attributed to component failure.

Even though, as shown, the current model provides for the allowance of a sufficient range of parts, there occurs a timing issue. The period of time between the model establishing an item as allowable and the ILO during which the part might actually be allowed may be years. As a temporary action, the following recommendation is offered.

Recommendation 2 -- Pending ILO update of the COSAL allowances, the Type Commander should consider for 'suite' inclusion any *Not Allowed* part demanded for selected critical systems by ships in the classes concerned.

Recommendation 3 -- SPCC and NAMSO should undertake an effort to determine the feasibility of a data link to ensure that, in the future, demand data for CASREP requisitions is entered into the Maintenance Data Collection System files. No demands made upon the system are so critical to future allowance decisions as those which were required to correct a casualty.

Recommendation 4 -- A significant effort should be undertaken to determine an average cost for a ship which is unable to perform its mission due to a casualty. Some of the questions involved are:

- Is the cost different for different classes of ships?
- Does the cost vary by mission?
- How many of the identifiable costs are fixed, and thereby excluded from consideration?
- What costs should be included, and how far up the supply/logistics chain should they reach?

Recommendation 5 -- A statistically valid survey of ships and APLs for the entire fleet should be undertaken to determine the extent to which CASREP demands fail to be recorded in the MDCS system. Such a survey could reveal a significant failure within the system, the result of which might be significant allowance shortfalls of critical parts.

B. SUMMARY

Determining the correct depth and range of parts to carry onboard any Navy vessel is a problem of herculean proportions. Years of effort on the part of Navy logisticians at all levels have resulted in the models investigated herein, as well as many others in use. The failure of a ship to meet a mission commitment because a part is not carried is unavoidable, but the probabilities can be decreased by following proper procedures. It was the purpose of this research to determine, in one small area, if additional protection could be afforded a specific class of ships.

The research showed that the Mod-FLSIP COSAL allowance model provided sufficient range to protect the APLs submitted for test, but that not all demands were being recorded. Prior to the implementation of the $\mu = .1$ parameter, several of the components would have been excluded which are now allowed. As a result, I

concluded that no reasonable method existed to provided, based upon available usage or criticality data, a 'suite' of repair parts.

I recommended that additional research be undertaken to further define the costs of casualties, and to determine those NIINs which have shown themselves to require an allowance, but which, through administrative error, have not yet qualified.

Attempting to second-guess the reliability of the highly complex and very technical systems which make up the engineering plants of the gas-turbine ships will be frustrating, costly and fraught with human error. I believe it is best to remain with the statistically proven, if not always correct, models which provide for spare parts allowances. Based upon historical demand and engineering estimates, these models stock our storerooms and keep our ships at a high state of readiness within the confines of limited resources and ever-tightening budget constraints.

APPENDIX A
MOD-FLSIP COSAL ALLOWANCE COMPUTATIONS

APL 052050008	POP: 4	UNIT				ALLOWANCE	
COG NIIN	QTY	PRICE	MRU	BRF	MU	DEMAND	SAFETY
9V 00-111-5700	1	$8.83	1	.1	.1	0	1
1H 00-615-0656	2	$7.00	2	.2	.2	0	2
9Z 00-020-0067	2	$.12	1	.2	.2	0	1
9Z 00-020-0105	1	$.11	1	.1	.1	0	1
9Z 00-020-0186	3	$.07	1	.3	.3	0	1
9Z 00-020-0203	10	$.06	3	1	1	2	0
9Z 00-066-9611	2	$8.13	2	.2	.2	0	2
9Z 00-078-3613	100	$.33	100	10	10	15	0
9Z 00-079-9961	4	$.27	4	.4	.4	0	4
9V 00-106-6552	1	$.61	1	.1	.1	0	1
9V 00-106-8818	1	$2.67	1	.1	.1	0	1
9Z 00-109-8914	1	$30.00	1	.1	.1	0	1
9V 00-110-2924	5	$5.67	2	.5	.5	0	4
9V 00-110-6222	6	$22.25	1	.6	.6	0	2
9V 00-110-8971	2	$5.33	2	.2	.2	0	2
9Z 00-111-5690	2	$1.53	2	.2	.2	0	2
9V 00-111-5729	32	$2.55	8	3.2	3.2	6	0
9V 00-112-2133	2	$.87	1	.2	.2	0	1
9V 00-112-9775	1	$1.48	1	.1	.1	0	1
9V 00-113-1710	3	$.49	1	.3	.3	0	1
9V 00-113-4147	2	$6.51	2	.2	.2	0	2
9V 00-115-3196	2	$4.84	2	.2	.2	0	2
9V 00-118-3177	1	$.14	1	.1	.1	0	1
9V 00-130-8197	4	$1.25	1	.4	.4	0	1
9Z 00-166-1063	30	$.09	30	3	3	5	0
9Z 00-166-8422	2	$.33	2	.2	.2	0	2
9Z 00-167-0812	1	$.47	1	.1	.1	0	1
9V 00-182-5362	7	$.21	7	.7	.7	0	14
9Z 00-194-1675	1	$.37	1	.1	.1	0	1
9Q 00-305-2306	4	$13.52	4	.4	.4	0	4
9V 00-439-5249	10	$.43	10	1	1	2	0
9V 00-448-0530	3	$.69	3	.3	.3	0	3
9V 00-450-4547	4	$10.73	4	.4	.4	0	4
9V 00-450-4588	7	$.23	7	.7	.7	0	14
9V 00-460-3427	5	$.41	5	.5	.5	0	10
9G 00-480-1329	10	$3.82	10	1	1	2	0
9Z 00-515-7449	1	$.48	1	.1	.1	0	1
9V 00-583-5551	1	$4.08	1	.1	.1	0	1
7H 00-596-6273	1	$2,990.00	1	.1	.1	0	1
1H 00-596-6452	5	$97.00	2	.5	.5	0	4
1H 00-596-6555	1	$13.50	1	.1	.1	0	1
1H 00-596-6558	1	$13.00	1	.1	.1	0	1
1H 00-601-1048	1	$2,080.00	1	.1	.1	0	1
7H 00-601-1236	2	$3,250.00	1	.2	.2	0	1
7H 00-601-1294	1	$502.00	1	.1	.1	0	1

1H	00-601-1365	1	$1,050.00	1	.1	.1	0	1
1H	00-601-1411	1	$500.00	1	.1	.1	0	1
2H	00-601-1525	1	$774.00	1	.1	.1	0	1
2H	00-601-1563	1	$499.00	1	.1	.1	0	1
1H	00-602-6653	1	$1,130.00	1	.1	.1	0	1
1H	00-602-7372	1	$99.00	1	.1	.1	0	1
1H	00-610-2941	4	$44.00	4	.4	.4	0	4
1H	00-610-2966	2	$12.00	1	.2	.2	0	1
7H	00-613-7235	1	$997.00	1	.1	.1	0	1
1H	00-613-7282	15	$.73	10	1.5	1.5	3	0
1H	00-615-0626	4	$.76	2	.4	.4	0	2
1H	00-615-0656	5	$7.30	4	.5	.5	0	8
1H	00-616-2373	1	$123.00	1	.1	.1	0	1
1H	00-616-3322	1	$.25	1	.1	.1	0	1
1H	00-616-3602	2	$12.00	1	.2	.2	0	1
1H	00-616-3632	1	$22.00	1	.1	.1	0	1
1H	00-616-3773	1	$8.50	1	.1	.1	0	1
1H	00-616-3788	1	$18.50	1	.1	.1	0	1
9Z	00-617-8200	1	$21.35	1	.1	.1	0	1
9Z	00-617-8205	1	$13.20	1	.1	.1	0	1
9Z	00-618-0475	2	$1.19	2	.2	.2	0	2
9Z	00-618-9479	18	$4.01	2	1.8	1.8	4	0
1H	00-625-6442	1	$8.50	1	.1	.1	0	1
1H	00-625-6443	1	$59.00	1	.1	.1	0	1
9Z	00-629-9907	3	$14.03	1	.3	.3	0	1
9V	00-796-4415	6	$.67	3	.6	.6	0	6
9V	00-821-3889	1	$1.93	1	.1	.1	0	1
9C	00-843-9837	2	$1.68	2	.2	.2	0	2
9Z	00-851-5586	3	$.10	1	.3	.3	0	1
9Z	00-890-8102	4	$.59	1	.4	.4	0	1
9V	00-935-9446	1	$9.44	1	.1	.1	0	1
9Z	00-985-6596	2	$8.37	2	.2	.2	0	2
1H	01-003-5732	4	$459.00	4	.4	.4	0	4
9Z	01-009-6741	3	$1.17	1	.3	.3	0	1
9Z	01-009-6742	1	$1.34	1	.1	.1	0	1
1H	01-015-7434	5	$16.00	5	.5	.5	0	10
1H	01-015-7685	5	$18.50	5	.5	.5	0	10
1H	01-019-8735	9	$325.00	3	.9	.9	0	6
9Z	01-027-4695	1	$.05	1	.1	.1	0	1
1H	01-058-1718	4	$229.00	4	.4	.4	0	4
9Z	01-080-9154	10	$13.97	10	.4	.4	0	10
9V	00-113-6438	2	$.12	2	.2	.2	0	2

APL 616050177C	POP: 1	UNIT				ALLOWANCE	
COG NIIN	QTY	PRICE	MRU	BRF	MU	DEMAND	SAFETY
7H 01-016-6231	1	$950.00	1	.1	.025	0	1
7H 01-076-5612	1	$5,890.00	1	.1	.025	0	1

APL 701110382	POP: 4	UNIT				ALLOWANCE	
COG NIIN	QTY	PRICE	MRU	BRF	MU	DEMAND	SAFETY
9V 00-110-6222	3	$17.35	1	.3	.3	0	1
9V 00-111-1197	1	$2.69	1	.1	.1	0	1
9V 00-144-1451	2	$.75	2	.2	.2	0	2
9Z 00-167-0814	1	$.56	1	.1	.1	0	1
7H 00-205-3244	1	$5,420.00	1	.1	.1	0	1
2H 00-601-1084	5	$25,790.00	1	.5	.5	0	2
9Z 00-850-3746	2	$.21	2	.2	.2	0	2
9Z 00-881-3024	1	$.33	1	.1	.1	0	1
9Z 00-882-9129	12	$.07	12	1.2	1.2	3	0
9Z 00-890-8102	2	$.61	2	.2	.2	0	2
9Z 00-928-7109	16	$.17	16	1.6	1.6	3	0
9V 01-005-8195	1	$.64	1	.1	.1	0	1
9Z 01-020-4680	4	$1.52	4	.4	.4	0	4
9Z 01-020-5265	4	$4.11	4	.4	.4	0	4
9Z 01-020-5266	4	$1.60	4	.4	.4	0	4
9Z 01-020-5952	4	$1.85	4	.4	.4	0	4
7H 01-064-0287	1	$36,900.00	1	.1	.1	0	1

APL 701110383	POP: 4	UNIT				ALLOWANCE	
COG NIIN	QTY	PRICE	MRU	BRF	MU	DEMAND	SAFETY
9V 00-118-3177	1	$.10	1	.1	.1	0	1
7H 00-601-1236	1	$2,220.00	1	.1	.1	0	1
9G 01-005-8617	1	$256.40	1	.1	.1	0	1
9V 00-821-3889	1	$1.78	1	.1	.1	0	1

APPENDIX B

TRIDENT COSAL ALLOWANCE COMPUTATIONS

APL:052050008		POP: 4		MIL.ESSENT.			ALLOWANCES *		
COG	NIIN	QTY	MU	COUPLETS		MEC	(1)	(2)	(3)
9V	00-111-5700	1	.1	21	12	101	2	1.7	.4
1H	00-615-0656	2	.2	21	21	107	3	2.9	.5
9Z	00-020-0067	2	.2	21	22	110	5	4.3	.5
9Z	00-020-0105	1	.1	21	22	110	4	3.1	.4
9Z	00-020-0186	3	.3	21	22	110	6	5.5	.5
9Z	00-020-0203	10	1	21	21	107	11	9.6	1.0
9Z	00-066-9611	2	.2	21	21	107	3	2.9	.5
9Z	00-078-3613	100	10	21	10	95	30	4.1	25.4
9Z	00-079-9961	4	.4	21	10	95	5	.8	4.0
9V	00-106-6552	1	.1	21	12	101	3	2.2	.4
9V	00-106-8818	1	.1	21	11	98	2	1.8	.4
9Z	00-109-8914	1	.1	21	22	110	2	1.9	.4
9V	00-110-2924	5	.5	21	22	110	6	5.1	.6
9V	00-110-6222	6	.6	21	12	101	4	3.7	.7
9V	00-110-8971	2	.2	21	21	107	3	3.0	.5
9Z	00-111-5690	2	.2	21	22	110	4	3.6	.5
9V	00-111-5729	32	3.2	21	21	107	16	12.9	2.8
9V	00-112-2133	2	.2	21	22	110	4	3.8	.5
9V	00-112-9775	1	.1	21	12	101	3	2.1	.4
9V	00-113-1710	3	.3	21	22	110	5	4.8	.5
9V	00-113-4147	2	.2	21	22	110	4	3.2	.5
9V	00-115-3196	2	.2	21	12	101	3	2.6	.5
9V	00-118-3177	1	.1	21	12	101	3	2.6	.4
9V	00-130-8197	4	.4	21	22	110	6	5.2	.6
9Z	00-166-1063	30	3	21	22	110	20	17.1	2.6
9Z	00-166-8422	2	.2	21	22	110	5	4.0	.5
9Z	00-167-0812	1	.1	21	10	95	2	.4	2.0
9V	00-182-5362	7	.7	21	11	98	7	6.1	.8
9Z	00-194-1675	1	.1	21	22	110	3	2.8	.4
9Q	00-305-2306	4	.4	21	10	95	3	.8	2.4
9V	00-439-5249	10	1	21	11	98	8	6.9	1.0
9V	00-448-0530	3	.3	21	11	98	4	3.6	.5
9V	00-450-4547	4	.4	21	21	107	5	4.0	.6
9V	00-450-4588	7	.7	21	11	98	7	6.1	.8
9V	00-460-3427	5	.5	21	11	98	6	4.9	.6
9G	00-480-1329	10	1	21	10	95	6	1.3	4.6
9Z	00-515-7449	1	.1	21	10	95	2	.4	2.0
9V	00-583-5551	1	.1	21	12	101	2	1.9	.4
7H	00-596-6273	1	.1	21	22	110	1	1.0	.4
1H	00-596-6452	5	.5	21	22	110	4	3.8	.6

* NOTES AT END OF TABLES

APL:052050008		POP: 4		MIL.ESSENT.			ALLOWANCES		
COG	NIIN	QTY	MU	COUPLETS		MEC	(1)	(2)	(3)
1H	00-596-6555	1	.1	21	22	110	3	2.1	.4
1H	00-596-6558	1	.1	21	22	110	3	2.1	.4
1H	00-601-1048	1	.1	21	22	110	1	1.0	.4
7H	00-601-1236	2	.2	21	22	110	2	1.4	.5
7H	00-601-1294	1	.1	21	22	110	2	1.3	.4
1H	00-601-1365	1	.1	21	22	110	2	1.2	.4
1H	00-601-1411	1	.1	21	22	110	2	1.3	.4
2H	00-601-1525	1	.1	21	22	110	2	1.3	.4
2H	00-601-1563	1	.1	21	22	110	2	1.3	.4
1H	00-602-6653	1	.1	21	22	110	2	1.2	.4
1H	00-602-7372	1	.1	21	22	110	2	1.7	.4
1H	00-610-2941	4	.4	21	11	98	3	2.4	.6
1H	00-610-2966	2	.2	21	12	101	3	2.3	.5
7H	00-613-7235	1	.1	21	22	110	2	1.2	.4
1H	00-613-7282	15	1.5	21	11	98	9	8.0	1.4
1H	00-615-0626	4	.4	21	22	110	6	5.4	.6
1H	00-615-0656	5	.5	21	22	110	6	5.0	.6
1H	00-616-2373	1	.1	21	12	101	2	1.2	.4
1H	00-616-3322	1	.1	21	10	95	3	.4	2.1
1H	00-616-3602	2	.2	21	22	110	3	3.0	.5
1H	00-616-3632	1	.1	21	12	101	2	1.5	.4
1H	00-616-3773	1	.1	21	22	110	3	2.2	.4
1H	00-616-3788	1	.1	21	12	101	2	1.6	.4
9Z	00-617-8200	1	.1	21	11	98	2	1.4	.4
9Z	00-617-8205	1	.1	21	11	98	2	1.5	.4
9Z	00-618-0475	2	.2	21	10	95	3	.6	2.4
9Z	00-618-9479	18	1.8	21	12	101	10	7.9	1.6
1H	00-625-6442	1	.1	21	12	101	2	1.7	.4
1H	00-625-6443	1	.1	21	12	101	2	1.3	.4
9Z	00-629-9907	3	.3	21	12	101	3	2.8	.5
9V	00-796-4415	6	.6	21	11	98	6	5.1	.7
9V	00-821-3889	1	.1	21	12	101	2	2.0	.4
9C	00-843-9837	2	.2	21	11	98	3	2.6	.5
9Z	00-851-5586	3	.3	21	22	110	6	5.4	.5
9Z	00-890-8102	4	.4	21	12	101	5	4.5	.6
9V	00-935-9446	1	.1	21	22	110	3	2.2	.4
9Z	00-985-6596	2	.2	21	22	110	4	3.1	.5
1H	01-003-5732	4	.4	21	22	110	3	2.7	.6
9Z	01-009-6741	3	.3	21	12	101	4	3.7	.5
9Z	01-009-6742	1	.1	21	12	101	3	2.1	.4
1H	01-015-7434	5	.5	21	12	101	4	3.5	.6
1H	01-015-7685	5	.5	21	12	101	4	3.5	.6
1H	01-019-8735	9	.9	21	22	110	5	4.3	.9
9Z	01-027-4695	1	.1	21	22	110	4	3.2	.4
1H	01-058-1718	4	.4	21	22	110	4	3.0	.6
9Z	01-080-9154	10	.4	21	11	98	3	2.9	.6
9V	00-113-6438	2	.2	21	22	110	5	4.3	.5

APL:616050177C		POP: 1		MIL.ESSENT.			ALLOWANCES		
COG	NIIN	QTY	MU	COUPLETS		MEC	(1)	(2)	(3)
7H	01-016-6231	1.025		22	22	116	1	.8	.4
7H	01-076-5612	1.025		22	22	116	1	.6	.4

APL:701110382		POP: 4		MIL.ESSENT.			ALLOWANCES		
COG	NIIN	QTY	MU	COUPLETS		MEC	(1)	(2)	(3)
9V	00-110-6222	3	.3	21	21	107	4	3.3	.5
9V	00-111-1197	1	.1	21	22	110	3	2.4	.4
9V	00-144-1451	2	.2	21	11	98	3	2.9	.5
9Z	00-167-0814	1	.1	21	10	95	2	.4	2.0
7H	00-205-3244	1	.1	21	22	110	1	.9	.4
2H	00-601-1084	5	.5	21	22	110	1	.1	.6
9Z	00-850-3746	2	.2	21	21	107	4	3.9	.5
9Z	00-881-3024	1	.1	21	11	98	3	2.2	.4
9Z	00-882-9129	12	1.2	21	11	98	10	8.8	1.2
9Z	00-890-8102	2	.2	21	21	107	4	3.6	.5
9Z	00-928-7109	16	1.6	21	21	107	13	11.3	1.5
9V	01-005-8195	1	.1	21	22	110	3	2.7	.4
9Z	01-020-4680	4	.4	21	21	107	5	4.8	.6
9Z	01-020-5265	4	.4	21	21	107	5	4.4	.6
9Z	01-020-5266	4	.4	21	21	107	5	4.7	.6
9Z	01-020-5952	4	.4	21	21	107	5	4.7	.6
7H	01-064-0287	1	.1	21	22	110	1	.5	.4

APL:701110383		POP: 4		MIL.ESSENT.			ALLOWANCES		
COG	NIIN	QTY	MU	COUPLETS		MEC	(1)	(2)	(3)
9V	00-118-3177	1	.1	21	21	107	3	2.9	.4
7H	00-601-1236	1	.1	21	22	110	1	1.0	.4
9G	01-005-8617	1	.1	21	21	107	2	1.3	.4
9V	00-821-3889	1	.1	21	21	107	3	2.3	.4

NOTES: (1) Total COSAL Allowance Rounded to nearest whole number
(2) Safety Level
(3) Computed Demand Quantity

APPENDIX C

SUMMARY OF REPORTED CASREP INFORMATION

APL: 052050008

CASREP RATING	NIIN	COSAL ALLOWED	CASREP QTY	DEMAND LISTING
C-3	01-016-6235	NO	1	
	00-601-1279	NO	1	
C-2	00-602-6653	NO	1	YES
C-2	NONE LISTED			

APL: 701110382

CASREP RATING	NIIN	COSAL ALLOWED	CASREP QTY	DEMAND LISTING
C-3	01-117-5433	NO	1	
C-2	01-093-1372	1	1	
	01-111-8299	1	1	
	01-205-3244	NO	2	(NOTE 1)
	00-110-6222	1	1	YES
	01-140-6943	12	12	
C-2	01-064-0287	1	1	YES
	00-111-5729	8	22	
	00-613-7235	4	26	(NOTE 2)
	00-166-1063	NO	30	
	00-615-0656	4	26	(NOTE 3)
	01-174-4280	NO	1	
C-2	01-064-0287	1	1	YES

APL: 701110383

CASREP RATING	NIIN	COSAL ALLOWED	CASREP QTY	DEMAND LISTING
C-2	00-601-1236	1	1	YES
	01-125-0280	NO	1	
	01-128-3058	NO	1	

NOTES:

(1) Wrong NIIN reported.
(2) Unusual Demand. 4 allowed 7H DLR, 0 onboard, 26 requisitioned.
(3) Unusual Demand. 4 allowed, 4 onboard, 30 required.
(4) APLs 616050177C and 616050178C reported no CASREPs.

APPENDIX D
AN ALTERNATIVE MODEL

The overriding factor in these alternative models is the requirement that a Technical Override be utilized to cause any NIINs which meet the following criteria to be requisitioned. The only other alternative is for the Type Commander to order them. Any NIINs selected must be determined by engineering personnel based upon 'maintenance feel'. There is no way the supply system can be used to point to those parts which might be needed. I believe that I have shown, in the body of this thesis, that the system, as currently designed, works.

I developed two different methods of determining cost effectiveness of a 'suite' of parts. The first is the individual value of a NIIN against the probability of a casualty in the system.

The operation of the TRIDENT COSAL model depends upon material essentiality relationships rather than demand history for the determination of a safety level. I experimented with changes in the Z (normalized multiplier) value while attempting to simulate the same protection levels as the Mod-FLSIP model. I also demonstrated the effect of the price modifier (1.5 LOG p) in Table 6.

It was during this experimentation that I discovered a significant relationship between the safety level (S) and the price modifier. By setting S constant at .5 units, the minimum at which rounding would cause one MRU to be stocked, and solving for LOG P, I could determine the maximum price at which the desired protection level for any specified MEC would be obtained. The resulting formula for this price determination is:

$$\{8.8 - 1/6(116 - MEC) - 1.5\,x\} * D^{1/2} = .5$$

where

$$x = \text{Log P} \quad \text{and} \quad D = .01$$

I set D at .01 as the minimum required failure rate for the model to assure a protection level of 99.9% against any failure at all over a ten year period. In other words, I desired to model for .1 failures in ten years, that meaning the system would be covered for 99.9% of that period.

Using the MEC as a variable forced a different value for LOG P for each MEC value. The values computed are shown in Table 7 below.

TABLE 7

COMPUTED LOG_{10} P VALUES AND P VALUES

MEC	LOG P	P
116	2.53	$338.00
110	1.86	73.00
107	1.53	34.00
104	1.20	16.00
101	.86	7.00
98	.53	3.50
95	.20	1.50

Thus, any selected NIIN, the price of which does not exceed that associated with the MEC assigned it by the XY couplet method in Figure 3.2 might be presumed to have a value greater on board than the potential cost of an associated failure. This presumption is tenuous at best, but is a point from which the cost effectiveness of a 'suite' of critical parts might be begun.

For systems with established μ values based upon actual failure data, the dollar value will increase markedly. In fact, for a μ of .1, the formula allows a maximum value for MEC 95 of $300. Such recomputation of Log P values is left to the interested reader.

The second method determines the overall value of any 'suite' of parts based upon the cost to the Navy of a ship with a mission-threatening failure. The major failing of this method is the need for a finite cost of such a failure. For the purposes of demonstration, I utilized the following:

- A delay of 5 days pending arrival of parts.
- A cost of $50,000 per day for a ship to be unable to meet its mission objectives.
- A $2000 transportation cost to deliver required parts.

The total cost of a single failure with the above parameters is $232,000. I next assigned the 5 APLs utilized in the research the associated failure rates (λ). I computed λ by dividing the number of C3/C4 CASREPs by 10. By multiplying each λ with the total value and summing those products, I reached a total projected cost of failure per year. The example described above is shown in Table 8.

TABLE 8

TOTAL CASUALTY COST CALCULATION

APL	λ	Exp. Value
052050008	.1	$25200
701110382	.1	$25200
701110383	.1	$25200
616050177C	.01	$2520
616050178C	.01	$2520
TOTAL		$80640

If the projected price of the 'suite' of parts is less than the total projected cost of casualties, ($80,640), its value might be construed to be greater to the vessel than its cost. This presumption is also tenuous but, again, provides a starting place for determination of a 'suite' of critical parts.

A case might be made for combining the first and second methods to determine the maximum number of line items to be carried. I attempted this utilizing the percentage of each MEC in the sample data. The relationship can be made, but the number of line items is in excess of 20,000. Even using a μ of .1 in the calculations, the number of line items was still 110. While the relationship exists, it is not reasonable to mate the two in any realistic sense.

I have displayed these two methods of determining some cost effectiveness to show a possible relationship between failure rates and price. I do not recommend their utilization without significant further study into the actual cost of a ship in a C3 C4 status.

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